

A COMPARISON OF SOLAR ³HELIUM-RICH EVENTS WITH TYPE II BURSTS AND CORONAL MASS EJECTIONS

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ABSTRACT

It is generally presumed that $E \geq 1$ MeV per nucleon solar particle events of enhanced abundances, referred to as “³He-rich” or “Z-rich” events, are due to a two-step acceleration process. The first step selectively heats ³He and certain heavy ions such as Fe to a threshold energy for the second step, which then provides the bulk of the particle energization. If the second phase involves the same process that operates to produce energetic particle events of normal abundances, ³He-rich events should be significantly associated with both metric type II bursts and coronal mass ejections, as are solar energetic particle events of normal abundances. Using 66 ³He-rich periods observed on *ISEE 3* from 1979 to 1982, we find that these associations are due only to random chance unless the ³He-rich event is accompanied by an energetic proton event. This and other recent evidence indicates that enhanced abundance events may be produced only in the impulsive phases of flares, while normal abundance events are produced in subsequent flare shock waves.

Subject headings: Sun: corona — Sun: flares — Sun: radio radiation

1. INTRODUCTION

The physical origin of energetic (~ 10 MeV) particles produced in the solar corona and detected in interplanetary space remains unclear. However, two observational signatures now appear well associated with energetic proton events. Švestka and Fritzova-Švestkova (1974) concluded that 50%–75% of all proton events observed over a 30 month period were preceded by metric type II radio bursts. More recently, Kahler *et al.* (1984) found that nearly all flare proton events are associated with coronal mass ejections (CMEs). These observations suggest an important role for coronal shocks in proton acceleration.

Elemental and isotopic abundances found in large solar energetic particle events of $E \sim 1$ –10 MeV per nucleon (hereafter MeV n^{-1}) generally match accepted solar coronal, but not photospheric, abundances (Cook, Stone, and Vogt 1984). This is often not true for smaller events, however, where substantial enhancements of ³He/⁴He and $(Z > 6)/H$ over solar abundances are seen (Anglin, Dietrich, and Simpson 1977; Zwickl *et al.* 1978; Mason *et al.* 1980). Of particular interest are the “³He-rich” events, characterized by ³He/⁴He ≥ 0.2 , nearly three orders of magnitude larger than the solar wind or solar prominence values of 4×10^{-4} (Coplan *et al.* 1983; Hall 1975). The properties of these events were reviewed by Ramaty *et al.* (1980), who tabulated all ³He-rich events observed through 1976. This list was updated to 1980 in the recent review article by Kocharov and Kocharov (1984).

Several explanations have been advanced to account for these events with enhanced abundances. They generally invoke a two-step process consisting of ³He or high-Z enrichment

through nonthermal heating, followed by the second process, which provides most of the energization. As a first process Fisk (1978) proposed selective heating by a resonant interaction with ion cyclotron waves. Vavrogis and Papadopoulos (1983) considered the nonlinear physics of particle energization by ion cyclotron waves and found the dominant process to be non-resonant. This eliminated the requirement for exciting ⁴He⁺⁺ cyclotron waves in Fisk’s model. Alternative proposals by Ibragimov and Kocharov (1977) and Kocharov and Orishchenko (1983) invoked Langmuir waves and ion sound waves, respectively, for the initial heating process. However, Weatherall (1984) has shown that the velocity diffusion coefficient used by Ibragimov and Kocharov (1977) and by Kocharov and Orishchenko (1983) is not proportional to Z^4/A^2 , where Z is the charge and A the mass of the ion, but rather to Z^2/A^2 . Their mechanisms therefore do not have the required sensitivity to ion charge needed to account for the enhanced particle abundances. Melrose (1983) has argued that preacceleration mechanisms which draw a small fraction of the ions out of the tail of a Maxwellian distribution will lead to unacceptably low abundances for accelerated ions due to the slower speeds of the heavier ions. This conclusion holds for both events of normal and enhanced compositions.

An important question is whether the enhanced event ions are energized, after the presumed first-step heating, in the same way as ions in the larger cosmic-ray events of normal abundances. Studies of associated flares could be helpful in this regard, but, in contrast to the larger events, it is usually difficult to determine flare associations for the enhanced events. Probable H α source flares appear to be small subflares at well-connected longitudes (Zwickl *et al.* 1978), but the low particle fluxes and energies generally result in injection times too

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poorly determined to make specific flare associations (Anglin, Dietrich, and Simpson 1977). However, Kocharov and Kocharov (1984) identified parent solar flares for 18 cases in which short-duration ^3He -rich events were associated with energetic proton events. They found that type II bursts were associated with 40%–50% of those flares, a result reported earlier by Kocharov (1979). This suggests a common second step acceleration mechanism for normal and enhanced abundance events.

Statistical comparisons have also been used to suggest that the flare acceleration mechanism is the same for the two kinds of events. An observed similarity in their energy spectra led Zwickl *et al.* (1978) to suggest a common acceleration mechanism. Mason *et al.* (1980) pointed out that the variation of abundance ratios increases smoothly with decreasing size, giving no evidence that the small events represent a separate compositional class. They suggested that enhanced abundances may occur only over small regions and that if particles from only such a region are accelerated, an enhanced abundance event results. In the intense flux events, on the other hand, these particles are mixed with those from larger regions of normal abundances, and the result appears as an event of normal solar abundances. Implicit in the Mason *et al.* (1980) view is that both populations of particles are accelerated in the same mechanism.

In this paper we ask whether the energetic particles of ^3He -rich events are accelerated in the same process as that resulting in particles of normal-abundance events. We first present in § II a list of 66 ^3He -rich events observed with the Goddard Space Flight Center (GSFC) particle detector on *ISEE 3*. We then show that these events are not statistically associated with either of the two common signatures of normal-abundance events, metric type II bursts and coronal mass ejections. The implications of this result are discussed in § III.

II. DATA ANALYSIS

The 66 ^3He -rich events in the 1.3–1.6 MeV n^{-1} energy range were obtained from a survey of data from the *ISEE 3* very low-energy telescope (VLET). The detector was described by von Rosenvinge *et al.* (1978) and its elemental and isotopic resolution by von Rosenvinge and Reames (1979). The survey and the criteria for selecting the ^3He -rich periods were discussed in detail by Reames and von Rosenvinge (1983). The ^3He and ^4He fluxes were averaged in 6 hr intervals from 1978 August 15 to 1982 July 10. A ^3He -rich interval had to meet the following criteria: (1) the uncertainty in the ^3He flux was less than 50%; and (2) the $^3\text{He}/^4\text{He}$ ratio was ≥ 0.20 . Candidate ^3He -rich events, consisting of two or more successive ^3He -rich intervals, were observed with higher time resolution to identify obvious multiple events and define the onset times. The 66 events are listed in Table 1. The $^3\text{He}/^4\text{He}$ ratios of Table 1 are averaged over the event durations and are not corrected for ambient background levels. Only in about half the events (35) were distinct associated increases in the ^4He flux observed. These events are plotted in Figure 1. In the remaining 31 events, no accompanying increase in the ^4He flux was observed, so the resulting $^3\text{He}/^4\text{He}$ ratios are lower limits only. These events are noted in Table 1.

Only 15 of the 66 ^3He -rich events were accompanied by obvious $E \geq 1$ MeV proton events. These events are indicated in the last column of Table 1. Twelve of the 15 proton events are also associated with ^4He flux increases and shown in Figure 1. The median $^3\text{He}/^4\text{He}$ ratio for the 12 proton events is

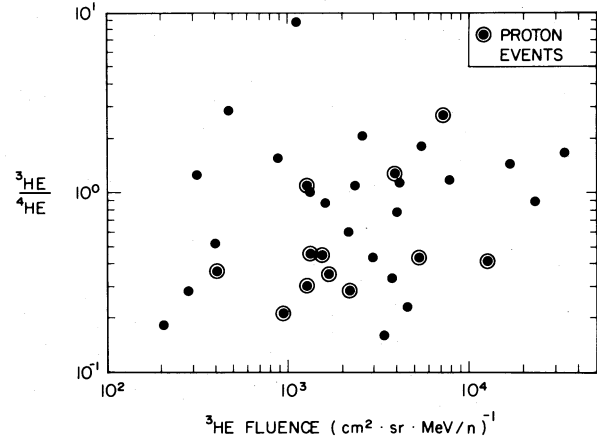


FIG. 1.—Average $^3\text{He}/^4\text{He}$ values vs. ^3He fluences for the events of Table 1 with observed ^4He flux increases. Events with accompanying proton events are indicated with circles. The median $^3\text{He}/^4\text{He}$ value for the proton event is 0.42; for all 35 events it is 0.76. The median ^3He fluence for the proton events is $1.6 \times 10^3 (\text{cm}^2 \text{ sr MeV n}^{-1})^{-1}$; for all 35 events it is $2.2 \times 10^3 (\text{cm}^2 \text{ sr MeV n}^{-1})^{-1}$.

0.42, compared to a higher value of 0.76 for all 35 events. The proton events are also associated with a smaller median ^3He fluence, $1.6 \times 10^3 (\text{cm}^2 \text{ sr MeV n}^{-1})^{-1}$, compared to $2.2 \times 10^3 (\text{cm}^2 \text{ sr MeV n}^{-1})^{-1}$ for all 35 events.

Multiple injections well associated with low-energy electron events (Reames, von Rosenvinge, and Lin 1984) characterize most ^3He -rich events. The electron associations, the occurrence of spike events, and, for larger events, the velocity dispersion and magnetic field-aligned arrival from the solar direction all suggest nearly scatter-free propagation from well-connected sources. In this study we use only the event onset times in our search for the solar signatures of ^3He -rich events. The approximate Sun–Earth propagation time for a 1.3 MeV n^{-1} particle is 3 hr. Allowing several hours for the uncertainty in the determination of event onset times and an additional several hours for possible coronal and interplanetary propagation, we select the time interval 0–10 hr prior to the event onset as the period to search for solar signatures of the ^3He -rich events.

a) Metric Type II Burst Associations

For each of the 66 events of Table 1 we looked for metric type II burst listings in *Solar-Geophysical Data* (1978–1982) during the 10 hr period preceding the event onset. We found type II bursts during 16 of these 66 periods. As control samples we also examined the same 10 hr time periods 1 day earlier and 1 day later for each event. As shown in Table 2, there were 12 type II bursts for the 66 10 hr periods 1 day earlier and another 12 bursts for the 66 periods 1 day later. The periods immediately preceding the ^3He -rich events therefore have only a few more type II bursts than the earlier and later control periods.

When we consider the proton-associated events separately, a different picture emerges. Six of the 15 events with protons were associated with type II bursts in the preceding 10 hr period, compared with only two for the preceding day and none for the following day. In addition, the event of 1980 March 25 1500 UT was probably associated with a type II burst at 0424 UT on that date, 10.6 hr prior to the ^3He event onset. Counting this event as associated, we get a total of seven of 15 proton events with type II bursts. This result is similar to

TABLE 1
 ISEE 3 ^3He EVENT LIST

^3He Onset Time (UT)	Duration (hr)	^3He Fluence ($\text{cm}^2 \text{ sr MeV n}^{-1}$) ⁻¹	Average $^3\text{He}/^4\text{He}$		Proton Events
1978 Oct 23 1600	24	1293.	1.10 \pm	0.19	yes
1978 Nov 3 0800	28	3884.	1.29	0.14	yes
1978 Nov 8 2200	24	411.	0.36	0.10	yes
1978 Nov 27 2000	24	766.	26.	+ 36. - 10. ^a	no
1978 Dec 26 1600	20	2589.	2.07	0.30	no
1979 Feb 6 0200	72	1314.	1.00	0.17	no
1979 Feb 10 0500	48	4127.	1.11	0.11	no
1979 Mar 24 < 1530	16	646.	5.6	+ 5.6 - 1.9 ^a	no
1979 May 17 0900	30	5118.	5.94	0.93 ^a	no
1979 Jun 11 2000	36	3776.	0.15	0.02 ^a	no
1979 Aug 15 0800	14	1892.	0.26	0.04 ^a	no
1979 Sep 6 1400	44	2924.	0.43	0.05	no
1979 Oct 3 1600	40	2155.	0.60	0.08	no
1979 Oct 5 1800	16	406.	0.28	0.08 ^a	no
1979 Oct 22 0000	72	879.	1.54	0.33	no
1979 Nov 3 2200	12	332.	0.34	0.11 ^a	no
1979 Dec 14 1200	36	33460.	1.67	0.07	no
1979 Dec 19 0400	12	476.	2.80	1.15	no
1979 Dec 20 2000	12	217.	0.32	0.11 ^a	yes
1979 Dec 23 1100	48	7259.	2.67	0.33	yes
1980 Jan 13 2400	32	5433.	1.80	0.18	no
1980 Feb 4 2300	16	3972.	0.96	0.10 ^a	no
1980 Feb 11 0400	36	1524.	0.60	0.09 ^a	no
1980 Feb 13 2000	12	2329.	1.09	0.14	no
1980 Mar 1 0800	36	1136.	8.80	3.12	no
1980 Mar 16 1000	32	317.	1.27	0.45	no
1980 Mar 25 1500	24	1515.	0.44	0.09	yes
1980 Mar 27 0200	36	761.	0.36	0.08 ^a	no
1980 Mar 29 0000	32	780.	1.25	0.30 ^a	yes
1980 Mar 30 1400	16	3916.	0.76	0.07	no
1980 Apr 2 2200	16	2945.	0.37	0.05 ^a	no
1980 Apr 12 1400	12	382.	0.38	0.11 ^a	no
1980 Apr 13 1300	8	206.	0.18	0.08	no
1980 Apr 15 0800	48	850.	0.45	0.09 ^a	yes
1980 Jun 23 0600	18	5394.	0.43	0.04	yes
1980 Jun 28 0200	28	951.	0.21	0.04	yes
1980 Jun 29 1600	18	1723.	0.35	0.05	yes
1980 Jul 9 0200	12	1288.	0.30	0.05	yes
1980 Nov 9 1700	20	16738.	1.43	0.08	no
1980 Nov 15 1300	8	4050.	1.27	0.14 ^a	no
1980 Dec 16 1900	16	1340.	0.45	0.08	yes
1980 Dec 20 1300	12	757.	1.25	0.29 ^a	no
1980 Dec 21 0400	44	1270.	0.77	0.13 ^a	no
1980 Dec 24 2000	36	612.	2.69	0.85 ^a	no
1981 Feb 5 1400	12	352.	1.49	0.57 ^a	no
1981 Mar 13 1800	18	575.	1.76	0.51 ^a	no
1981 Mar 23 0800	36	2211.	0.28	0.04	yes
1981 Jun 15 1800	18	979.	1.04	0.20 ^a	no
1981 Jun 18 0200	14	280.	0.28	0.09	no
1981 Jul 17 1200	20	390.	0.51	0.14	no
1981 Jul 20 0800	6	411.	32.	+ ∞ - 16. ^a	no
1981 Jul 31 > 0400	24	3727.	0.33	0.03	no
1981 Sep 2 1200	24	956.	0.39	0.08 ^a	no
1981 Sep 11 1600	12	816.	0.46	0.10 ^a	no
1981 Sep 13 0000	24	403.	0.64	0.18 ^a	no
1981 Sep 15 2200	36	7825.	1.17	0.10	no
1981 Nov 20 1330	36	3407.	0.16	0.02	no
1981 Dec 5 0600	12	396.	0.87	0.29 ^a	no
1982 Feb 12 0600	30	9602.	0.54	0.03 ^a	no
1982 Mar 5 < 0600	24	374.	4.0	+ 9.5 - 1.6 ^a	no
1982 Mar 10 1600	28	22718.	0.88	0.04	no
1982 Mar 18 2000	24	1333.	0.39	0.06 ^a	no
1982 Apr 3 1100	18	1397.	0.56	0.10 ^a	no
1982 Jun 25 0800	12	4533.	0.23	0.03	no
1982 Jun 25 2300	12	12787.	0.41	0.04	yes
1982 Jun 30 1300	12	1600.	0.88	0.14	no

^a No observed associated ^4He flux increases. The ratio is based on the ambient ^4He fluence.

TABLE 2
TYPE II BURST ASSOCIATIONS FOR THE ^3He EVENTS

Time Period Examined	All Events (66)	Events with MeV Protons (15)	Events with No MeV Protons (51)
0–10 hr prior to event onset	16	7 ^a	10
Same interval, 1 day earlier	12	2	10
Same interval, 1 day later	12	0	12

^a Includes the type II burst of 1980 Mar 25 0424 UT, which began 10.6 hr before the ^3He onset, but is considered associated with the parent flare of the particle event.

the 40%–50% figure for type II burst associations reported by Kocharov and Kocharov (1984) for proton-associated events, and is significantly above the random type II burst occurrence rate.

The expected type II association for proton events can be inferred from data in Švestka and Simon (1975). Using only their $E > 10$ MeV confirmed proton events for which the flare association is certain and for which dynamic spectra in the metric wavelength range are available, we find that 84 of 112 events, or 75%, were associated with reported type II bursts. Three of the 15 proton events of Table 1 could not be associated with either H α flares or type II bursts, so for the probable flare associations we get seven type II bursts for 12 proton flares, a rate lower than, but not inconsistent with, the Švestka and Simon association rate.

Type II burst associations for the 51 remaining events of Table 1 with no accompanying energetic protons are shown in the last column of Table 2. It is obvious that for the “pure” ^3He events there is no significant association with type II bursts.

b) Coronal Mass Ejection Associations

The Solwind coronagraph has been described by Sheeley *et al.* (1980). Since 1979 March it has provided images of the solar white light corona from 2.5 to 10 R_{\odot} with an angular resolution of 1/25 per pixel. CMEs are easily detected in differenced images obtained by subtracting a base image taken at the beginning or middle of each day from those taken in subsequent orbits. The data coverage is not uniform and numerous gaps exist, so it is necessary to assume the period of time prior to a subtracted image during which any CME could be detected in the image. In our case we take a relatively conservative time period of 3.0 hr.

A CME with a nominal speed of $\sim 400 \text{ km s}^{-1}$ travels about $2 R_{\odot} \text{ hr}^{-1}$, so to observe a CME in the Solwind coronagraph field of view, we must allow 1 hr from the time the CME leaves the Sun. To look for any CMEs leaving the solar disk in the period 0–10 hr prior to a ^3He -rich event onset, we look at the Solwind data during the period from 9 hr before to 1 hr after the event onset. Assuming that any CME will be observed in a Solwind subtracted image obtained up to 3 hr later, we found that some Solwind data coverage existed for 45 of the 66 events of Table 1. Nine of the 45 events were also proton events.

In each 10 hr time interval we looked for west limb CMEs on the assumption that the ^3He -rich event sources are well connected to the Earth. We first looked only for fast CMEs with speeds of $V \geq 400 \text{ km s}^{-1}$, those found to be associated with proton events (Kahler *et al.* 1984). Definite fast CMEs were found for only two events, those of 1979 November 3 and 1981 March 23. In addition, possible CMEs of undetermined speeds were found in the 10 hr periods preceding four other

events. Thus, only two to six of the 45 ^3He -rich events could be associated with fast west limb CMEs. This is far fewer than the 26 out of 27 cases for proton events with likely flare associations and 39 out of 50 cases for all proton events in the Kahler *et al.* (1984) study.

We also examined the occurrence rate of all west limb CMEs, regardless of speed, during the 10 hr periods preceding the 45 ^3He -rich events. CMEs were found for three of the nine proton events (with an average data coverage of 6.1 hr per event) and nine of the 36 nonproton events (with an average coverage of 7.5 hr per event). A total of 14 CMEs was observed in 324.2 hr, resulting in a rate of 1.04 ± 0.28 per day, closely matching the rate of 1.1 per day calculated for the 1979–1982 period, assuming, as we have, a 3 hr time coverage for each Solwind image (Howard *et al.* 1984). There is therefore no evidence of any enhanced rate of CME occurrence during the 10 hr periods preceding the ^3He -rich event onsets.

III. DISCUSSION

If ^3He particles were accelerated in the same kinds of events that produce normal-abundance energetic particle events, we should expect to see good correlations between the ^3He events and metric type II bursts and CMEs. The correlation of type II bursts and CMEs with energetic proton events is $\sim 75\%$ and $\geq 90\%$, respectively. However, the correlation we find for the ^3He event onsets yields only 24% and 4%–13% for the type II bursts and CMEs respectively, despite our use of very broad 10 hr time windows.

One might suppose that, because the particle fluxes of ^3He -rich events are generally smaller than those of normal abundance events, any associated type II bursts and CMEs may also be fainter and hence less likely to be observed. Several observational results argue against this interpretation. First, about 40% of all flares associated with type II bursts are subflares, and another 40% are class 1 events (Wright 1980). This suggests that even the very small flares producing ^3He events should be capable of generating observable type II bursts if the primary acceleration mechanism involves coronal shocks. Second, although CMEs too faint or small to be detected may in principle exist, those associated with proton events are nearly always the larger halo, loop, fan, or quadrant filler structures. Only one of the 25 CMEs associated with the likely proton flares of Kahler *et al.*'s (1984) study was a “spike” event, although the various kinds of spike structures constituted over 50% of the observable Solwind CMEs (Howard *et al.* 1984). Third, we found in Figure 1 that the proton events were statistically associated with smaller, not larger, ^3He fluences. This is not what we would expect if ^3He production takes place in association with normal proton flares of relatively small size. Finally, we might expect that a reasonable brightness range for the fainter type II bursts and CMEs

should still yield a significant enhancement above background for the type II burst and CME associations. This possibility is precluded by the fact that these associations are consistent with random-chance occurrences. The ^3He events, therefore, appear not to be produced in the same way as events of normal abundances.

Another definitive result concerning the injection of ^3He particles has been presented by Reames, von Rosenvinge, and Lin (1984). For 11 event onsets they find interplanetary injection times for the ^3He particles and 2–100 keV electrons detected at *ISEE 3* to be simultaneous to within ~ 20 minutes. This suggests that ^3He particles could be accelerated along with electrons in short bursts characterized by metric or dekametric type III solar radio bursts (Lin 1974). Type III bursts are sometimes closely temporally associated with impulsive ($\tau \approx 10$ –100 s) hard X-ray bursts due to 10–100 keV electrons (Kane 1981). It is now clear from γ -ray observations that both ions and electrons are produced in these phases (Forrest and Chupp 1983). Only a small fraction of the impulsive phase ions inferred from the γ -ray measurements are thought to escape to the interplanetary medium (von Rosenvinge, Ramaty, and Reames 1981), and acceleration in coronal shocks which follow the impulsive phase appears more likely for nearly all $E \approx 10$ MeV interplanetary particle events (Kahler *et al.* 1984). Acceleration of ^3He particles takes place in solar events far less energetic than those characterized by γ -rays or coronal shocks, but it seems reasonable that ions impulsively accelerated along with the 2–100 keV electrons escaping the corona along magnetically open field lines would also be expected to escape the corona. This appears a likely explanation for the results of Reames, von Rosenvinge, and Lin (1984).

Klecker *et al.* (1984) have recently studied the ionic charge composition of ^3He , ^4He , and Fe in five ^3He - and Fe-rich events. They found that essentially all the helium was doubly ionized, but the mean charge state of Fe was 19 ± 2 , a value significantly higher than that in events of normal abundances. Their result and the apparent close association of ^3He -rich events with the 2–100 keV electrons found by Reames, von Rosenvinge, and Lin (1984) suggest an origin for the ^3He - and Fe-rich events different from that of normal abundance events.

The results we have obtained provide further evidence for this view. Our result yields no insight into the detailed acceleration mechanisms for enhanced or normal abundance events, but it indicates that enhanced-event particles are not accelerated along with normal abundance particles. Our data further suggest the possibility that a large flare may give rise to both kinds of abundances, with the enhanced abundances produced in the early impulsive phase and the normal abundances in a subsequent coronal shock wave. We found that the ^3He -rich events with observable proton events were well associated with type II bursts, as were proton events of normal abundances. On the other hand, when no proton event was observed, the type II association was due only to random chance. If we have both “pure” and “mixed” ^3He -rich events, we should expect that the occurrence of an observable proton event is not dependent on the ^3He fluence since the two are produced in separate processes. We should also expect that when a proton event occurs, the $^3\text{He}/^4\text{He}$ ratio should tend to be smaller due to the mixing of particles of enhanced and normal abundances. As we saw in Figure 1 and reported in § II, both these expected results were found.

As a possible example of a mixed event, the temporal behavior of the large ^3He -rich event on 1974 May 9 was treated by Möbius *et al.* (1980) as due to a short time injection ($\tau \leq 15$ minutes) for the Z-rich population and a longer time injection ($\tau \approx 6$ hr) for the population of normal abundance. These different injection time scales do not preclude the possibility that both populations of particles were accelerated by the same basic process, but it would seem unlikely that they were accelerated together in a common event. If low intensities of enhanced abundances are produced along with intensities of normal abundances varying widely from event to event, we would expect to see the smooth increase in the variation of abundance ratios with decreasing event sizes as Mason *et al.* (1980) found.

Let us now consider the relevance of these results for Z-rich events. The relationship between ^3He -rich and Z-rich (usually meaning Fe-rich) events has generally been treated cautiously in the literature. Anglin, Dietrich, and Simpson (1977) plotted $\text{Fe}/^4\text{He}$ ratios against $^3\text{He}/^4\text{He}$ ratios for a large number of events and concluded that while ^3He -rich events are always Fe-rich, some Fe-rich events are not ^3He -rich. This conclusion has been widely accepted (Zwickl *et al.* 1978; Ramaty *et al.* 1980; McGuire 1983). Zwickl *et al.* (1978) also claimed to confirm that all identified ^3He -rich events are rich in $Z \geq 20$ nuclei. Based on this apparent asymmetry in the relationship of ^3He -rich and Fe-rich events, they proposed a subclass of Fe-rich events in addition to a subclass of ^3He -rich events.

A reexamination of the plot in Figure 5 of Anglin, Dietrich, and Simpson (1977) suggests that their conclusion that all ^3He -rich events are also Fe-rich is unjustified. Six of their $\text{Fe}/^4\text{He}$ ratios were only upper limits, and they did not define a numerical threshold for Fe-richness. In addition, the confirmation claimed by Zwickl *et al.* (1978) was based on only five events. Finally, Mason *et al.* (1980) have pointed out that the ^3He -rich event of 1974 October 5 appears without any measurable increase in heavy-nucleus fluxes. Contrary to the general consensus, we conclude that there are ^3He -rich events which are not Fe-rich and vice versa. A more appropriate description of the situation is that there is a correlation between ^3He -richness and Fe-richness, but it is not very strong, as Anglin, Dietrich, and Simpson (1977) and Reames and von Rosenvinge (1981) found. The symmetry of the correlation suggests, however, that ^3He -rich and Fe-rich events can be treated as a single class of events rather than as separate classes as Zwickl *et al.* (1978) suggested. This implies that the results we have discussed above for the ^3He -rich events can also be applied to the Fe-rich events as well.

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